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ENHANCEMENT OF POWER QUALITY USING MC-DPFC IN TRANSMISSION SYSTEM

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ABSTRACT

The Power Quality problems during the last two decades have been the major concern of the power consumer's point of view. The operation of power systems has become complex due to growing consumption of electric power and increase in number of non-linear loads. A new device within the flexible AC-transmission system (FACTS) family, named multi connected-Distributed Power-flow controller (MC-DPFC) is presented in this paper. MC-DPFC is obtained from the distributed power flow controller (DPFC) which is derived from unified power-flow controller (UPFC). DPFC can be considered as a UPFC with elimination of common dc link between the shunt and series controllers. The active power exchange between the shunt and series converters is done by the transmission line at third harmonic frequency in MC-DPFC where as in UPFC this is done by common DC link. The MC-DPFC function is similar to that of UPFC with several low power series converters where as UPFC consists of one series converter. Therefore, MC-DPFC includes multiple series converters and one shunt converter without common dc link to improve power quality. This automatically enables the MC-DPFC to full control on all the power system parameters and also increases the reliability of the device and reduces its cost simultaneously. In this paper the power quality issues like voltage sag, voltage swell, harmonics and LLL-G fault are considered and the issues are reduced and fault is cleared which enhances the power quality. The application of MC-DPFC in power quality enhancement is simulated in Matlab/ Simulink environment which show the effectiveness of the proposed structure.

***KEYWORDS:** FACTS (Flexible Ac-Transmission Systems), MC-DPFC (Multi Connected- Distributed Power Flow Converter), UPFC (Unified Power Flow Controller), Voltage Sag, Voltage Swell, Harmonics, LLL-G (Three Phase to Line) Fault, Power Quality*

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Original Article

INTRODUCTION

Now-a-days use of electric power increases day by day because of increase in electric customers. This development in electric utility encourages the entry of power quality issues in the power systems. From the customer point of view, the power quality issue is concerned about current, voltage or frequency deviation which leads to power failure. The power quality issues are solved by using flexible ac transmission systems (FACTS) [1] and custom power devices [2] which are used in transmission and distribution systems respectively. The flexible ac transmission systems (FACTS) technology performs more accurate in transmission systems which are one of the

applications of power electronics. The use of this technology is to control and regulate the electric variables in the power systems.

These FACTS devices are of two types. One is Thyristor controlled devices and other is Voltage source converters (VSC). The voltage source converters are of series, shunt, series-series and series-shunt controllers. The series controllers consists of Dynamic Voltage Restorer(DVR), Static Synchronous Series Compensator (SSSC) and these devices inject reactive voltage into the transmission line. The shunt controllers includes Static Compensator(STATCOM) and this injects reactive current into the transmission line. The series-series controllers consists of Interline Power Flow Controller(IPFC), Interline Power Quality Conditioner(IPQC) and the series-shunt controller consists of unified power quality conditioner (UPQC) & unified power flow controller (UPFC).

The unified power flow controller (UPFC) is a versatile device which is able to control the active and reactive power respectively and also control the voltage at the connection node [3]. The unified power flow controller (UPFC) is modelled by the combination of SSSC, STATCOM & a common dc link to allow the flow of active power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM in both the directions.

Due to the high cost and the susceptibility to failures the UPFC is not widely applied in practice. The distributed power flow controller (DPFC) is able to control system parameters like line impedance, transmission angle and bus voltage like UPFC. The common DC link between the shunt and series converters was eliminated in DPFC. The exchange of active power between the shunt and series converters is through the transmission line at the third-harmonic frequency [4].

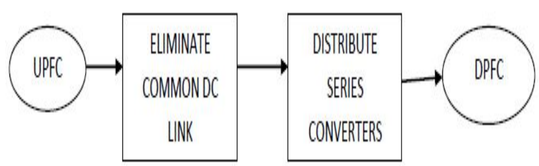

Figure 1: Flow Chart of DPFC from UPFC

The DPFC has the following advantages like: (1) the low voltage isolation and the low component rating of the series converters leads to low cost. (2) The redundancy of the series converters and high control capability leads to high reliability of the DPFC system. The power oscillation damping, voltage sag restoration or balancing asymmetry which leads to system stability and the power quality also improved by using the DPFC system. The DPFC system structure is having similar configuration to UPFC structure. The DPFC system consists of a single shunt controller and multiple independent series converters which are used to balance the line parameters, such as line impedance, transmission angle and bus voltage magnitude.

DPFC STRUCTURE

In the DPFC system, the transmission line is used as a connection between shunt converter output and AC port of series converters, instead of using DC link for power exchange between converters. The series converter employs the DSSC concept, which uses multiple single-phase converters instead of one three phase converter. Each converter within the DPFC is independent and has its own DC capacitor to provide the required DC voltage, while the shunt converter is

similar as a STATCOM. The transmission line presents a common connection between the AC ports of the shunt and the series converters in DPFC which leads to exchange of active power through the AC ports.

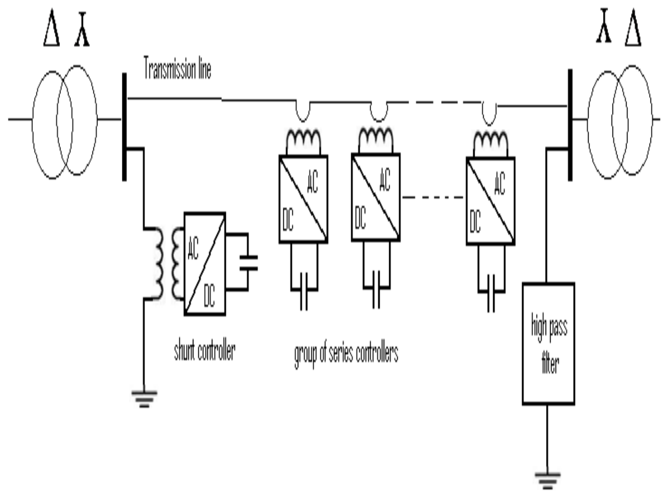

Figure 2: DPFC Configuration

This method is based on power theory of non-sinusoidal components. According to the Fourier series analysis, non-sinusoidal voltage and current can be expressed as the sum of sinusoidal functions in different frequencies with different amplitudes. This non-sinusoidal voltage and current is defined as the mean value of the product of voltage and current which results active power flow.

OPERATING PRINCIPLE OF MC-DPFC

The shunt converter can absorb active power from the grid at the fundamental frequency and inject the power back at a harmonic frequency. This harmonic active power flows through a transmission line connected with series converters. According to the amount of required active power at the fundamental frequency, series converters generate a voltage at the harmonic frequency, there by absorbing the active power from harmonic components [10]. The active power generated at the fundamental frequency is equal to the power absorbed at the harmonic frequency by neglecting losses.

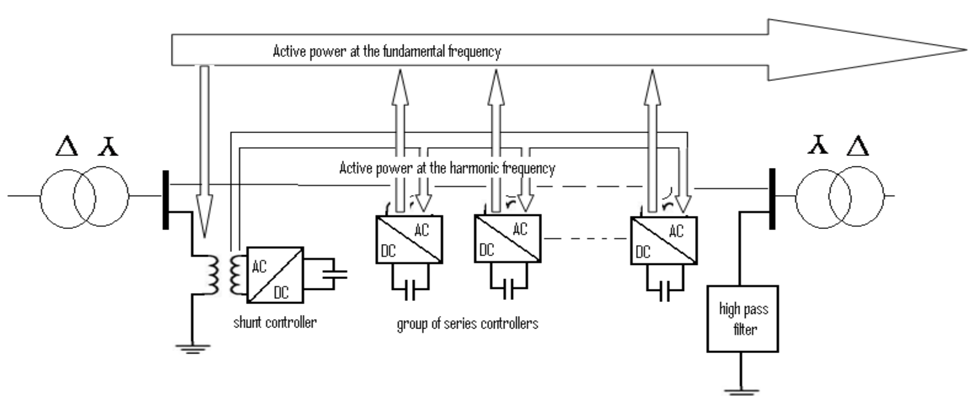

Figure 3: Active Power Exchange between DPFC Converters

In the DPFC system, the active power is exchanged between the shunt and the series converters. The high-pass filter in the DPFC blocks the fundamental frequency components and allows the harmonic components to pass, thereby providing a return path for the harmonic components. The shunt and series converters, the high pass filter and the ground form a closed loop for the harmonic current in the DPFC system. The 3^{rd} harmonic is selected for active power exchange in the DPFC due to the unique features of 3^{rd} harmonic frequency components in a three phase system. The 3^{rd} harmonic components lead to zero sequence components because the 3^{rd} harmonic components are identical in all three phases. The 3^{rd}, 6^{th}, 9^{th} Harmonics are all zero-sequence components and can be used to exchange active power in the DPFC system. In those the 3^{rd} harmonic is selected, because of its low frequency among all the zero-sequence harmonics. The expression for active power at the i^{th} harmonic frequency P_i and the voltages generated by the converters is

$$P=\sum_{i=1}^{\infty} V_i \; I_i \cos\Phi_i$$

Where V_i and I_i are the voltage and current at the i^{th} harmonic frequency respectively, and Φ_i is the corres ponding angle between the voltage and current. From the above equation it is clear that the active powers at different frequencies are independent from each other and the voltage or current at one frequency has no influence on the active power at other frequencies. By applying this method of calculating of active power of the DPFC, the shunt converter can absorb active power from the grid at the fundamental frequency and inject the power back at a harmonic frequency.

The impedance of the line limits the active power exchange capacity. To exchange the same amount of active power, the higher impedance line will requires higher voltages. Due to the transmission line impedance is mostly inductive and proportional to frequency, high transmission frequencies will cause high impedance and result in high voltage within converters. So, the zero-sequence harmonic with the lowest frequency i.e. the 3^{rd} harmonic has been selected.

Each converter is independent and has a separate DC link capacitor to provide the required DC voltage. The DPFC has the same control capability as the UPFC device, a method that allows the exchange of active power between converters without DC link is the prerequisite. In DPFC the series converters redundancy increases the system reliability during converter operation which means if one of series converter fails to operate, then the other converters can continue to work.

CONTROL CIRCUIT FOR MC-DPFC SYSTEM

The DPFC system consists of three controllers: central controller, series controller and shunt controller as shown in Figure [6].

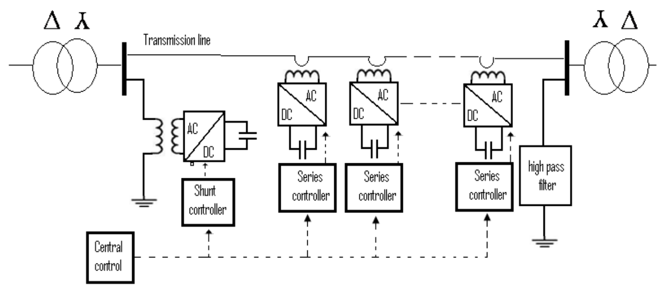

Figure 4: DPFC Controller Scheme

The central converter will regulate the DPFC functions at the power system level. The series and shunt controllers are localized controllers and are responsible for maintaining their own converter parameters [8].

Central Converter

This unit generates the reference signals for both the shunt and series converters of the DPFC system. Its control function depends on the specifics of the DPFC system application at the power system level, such as power flow control, low frequency power oscillation damping and balancing of asymmetrical components [5]. Depends on the system requirements, the central control gives corresponding voltage reference signals for the series converters and reactive current signal for the shunt converter. This central controller generates the reference signals with the concern of the fundamental frequency components.

Series Controller

Each series converter has its own controller. By using 3rd harmonic frequency components, the controller is used to maintain the capacitor DC voltage of its own converter, in addition to the generating series voltage at the fundamental frequency as required by the central control[6]. The inputs of this controller are series capacitor voltages, line currents and series voltage reference in dq-frame. The series controller has one low pass and one 3rd order bands pass filter to create fundamental and third harmonic current respectively. Single-phase Phase Locked Loop (PLL) is used to take frequency and phase information from the network [7]. It consists of one controller for each phase; if one fails to work and other two controllers will continue to work there by provides reliability.

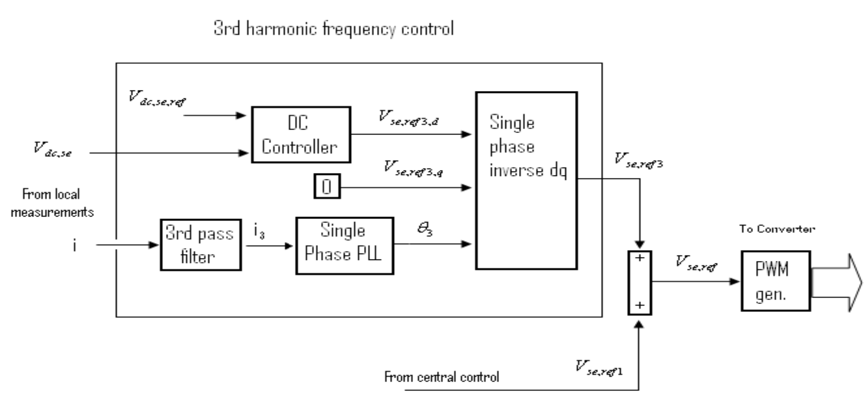

Figure 5: Series Controller

The working of series controller is like DVR (Dynamic voltage restorer) in transmission lines i.e. it controls the voltage in the transmission lines. If voltage swell occurs in the line, it injects the voltage into the line whereas voltage swell occurs in the line then it absorbs the voltage and stored in a capacitor which is useful whenever the sag condition appears.

Shunt Controller

The purpose of this unit is to inject a constant 3rd harmonic current into the line to supply active power for the series converters. It maintains the capacitor DC voltage of the shunt converter at a constant value by absorbing active power from the grid at the fundamental frequency and injecting the required reactive current at the fundamental frequency at the grid.

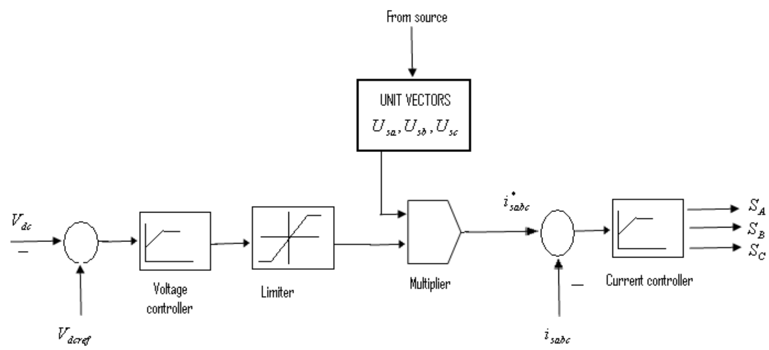

Figure 6: Shunt Controller

The shunt connected STATCOM with battery energy storage is connected at the PCC in the grid system with the non-linear load. The STATCOM compensator output is varies depends on the controlled strategy, so as to maintain the power quality norms in the grid system [9]. The current control strategy is obtained from the controller which defines the functional operation of the STATCOM compensator in the power system. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support to the DPFC system.

SIMULATION RESULTS

The case study, sag and swell conditions are implemented in single machine infinite bus system and analysed results are as follows [8]. The voltage sag and voltage swell are created to analyse the performance of the MC- DPFC system in line 1, as shown in Figure 7. The voltage sag is created for duration of 0.1 seconds (100-200 ms) and the voltage swell is created for duration of 0.1 seconds (200-300ms).

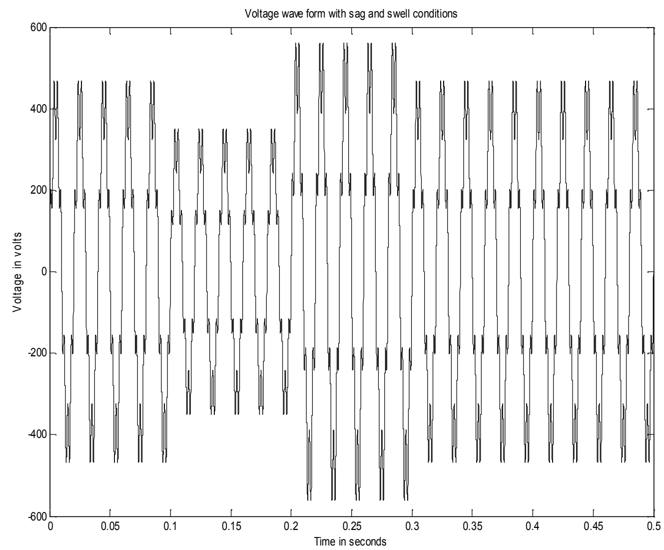

Figure 7: Voltages Sag and Swell Conditions in Line1 before Control

The MC-DPFC can compensate the load voltage sag and swell effectively. The mitigation with MC-DPFC [11] is shown in Figure 8 for line 1.

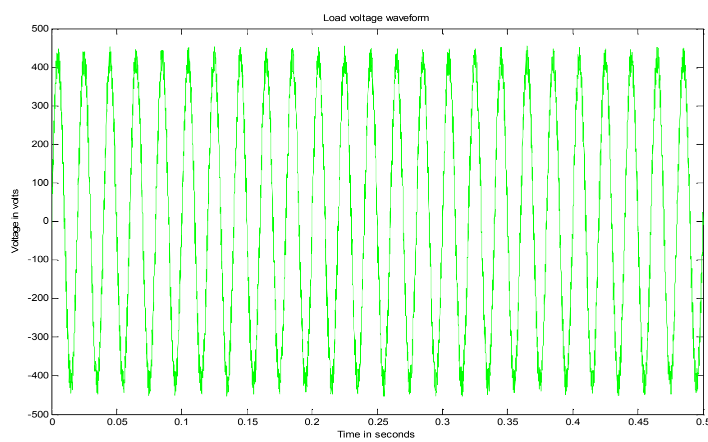

Figure 8: Load Voltage after Using DPFC System for Line 1

The load voltage harmonic analysis, using Fast Fourier transform (FFT) of power GUI window by *Simulink*, as shown in Figure 9. It can be seen, after MC-DPFC implementation in system, the odd harmonics are reduced within acceptable limits and total harmonic distortion (THD) of load voltage is minimized in line1.

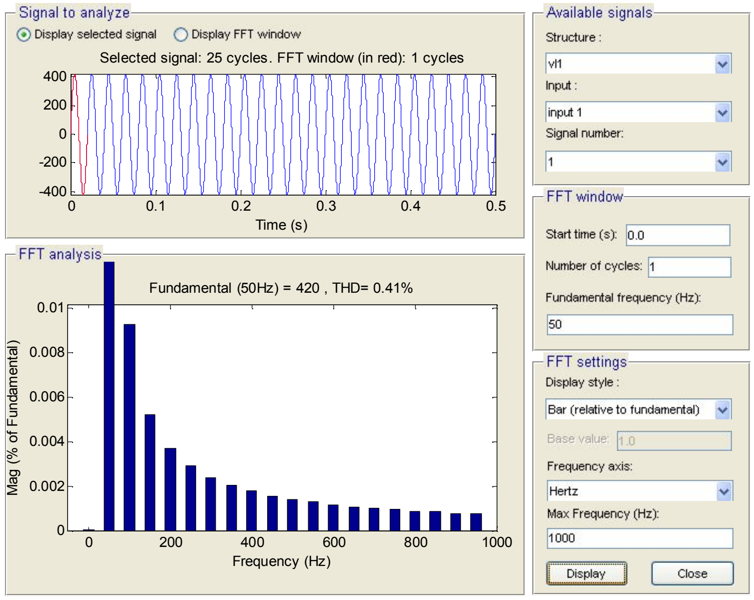

Figure 9: THD Performance of Load Voltage in Line 1

In the same way, the voltage sag, voltage swell and fault are created to analyse the performance of the MC-DPFC system in line 2, as shown in Figure 10. The voltage sag is created for duration of 0.1 seconds (100-200 ms) and the voltage swell is created for duration of 0.1 seconds (200-300ms) and the fault is created for duration of 0.1 seconds (300-400ms). The MC-DPFC compensates all these power quality issues effectively and the mitigated voltage is shown in figure 11.

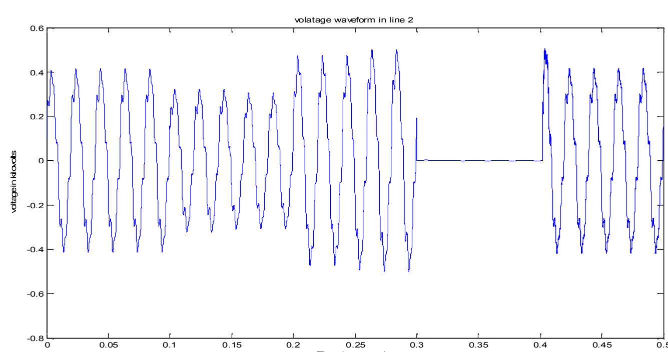

Figure 10: Voltage in Line2 before Control

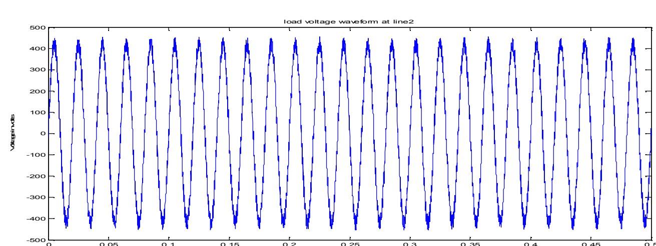

Figure 11: Load Voltage after Using DPFC System for Line2

The load voltage harmonic analysis, using Fast Fourier transform (FFT) of power GUI window by *Simulink*, as shown in Figure 12. It can be seen, after MC-DPFC implementation in system, the odd harmonics are reduced within acceptable limits and total harmonic distortion (THD) of load voltage is minimized in line2.

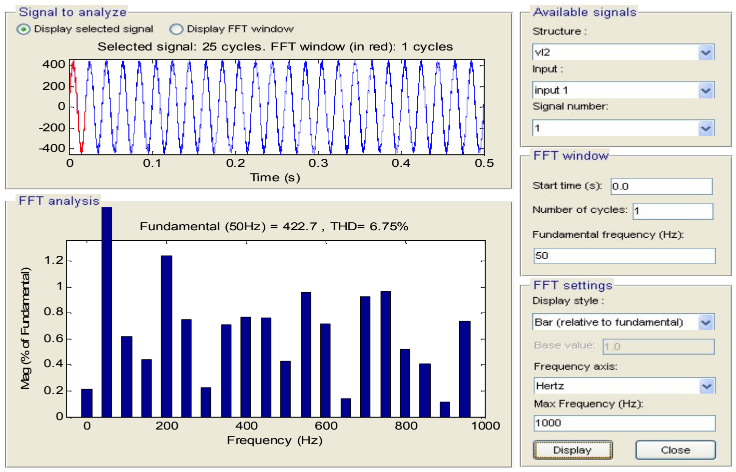

Figure 12: THD Performance of Load Voltage in Line2

The MC-DPFC system can mitigate all the power quality issues in both the lines. The FFT analysis is also done to the load voltages in both the lines. This type system is used in substations where more than one generating station is held, for example one substation has both wind and hydro power as sources respectively. The first line transmits wind power i.e. non conventional source energy which needs full control whereas the second line transmits the hydro power i.e. conventional source of energy which needs moderate control. So the MC-DPFC acts as DPFC for line1 whereas it acts as STATCOM for line2. Here the simulation system parameters are mentioned.

Table 1: Simulation System Parameters

Parameters	Values
Rated Voltage	25kV
Rated Power/Frequency	250 MVA/ 50 HZ
Transmission line inductance	0.06 p.u.
Type of Fault	ABC-G(LLL-G FAULT)
Ground Resistance	0.01 Ω
Fault resistance	0.01 Ω

CONCLUSIONS

In this paper, enhancement of power quality issues like voltage sag and swell, harmonics and fault conditions are simulated in Matlab/Simulink environment employing a new FACTS device named Multi connected-Distributed Power Flow Controller (MC-DPFC). The MC-DPFC is emerged from the UPFC and inherits the control capability of the UPFC, which is the simultaneous adjustment of the line voltage magnitude. The series converter of the DPFC employs the D-FACTS concept, which uses multiple small single phase converters instead of one large size converter. It is proved that the shunt and series converters in the MC-DPFC can exchange active power at the third harmonic frequency, and the series converters are able to inject controllable active and reactive power

at the fundamental frequency. In this the MC-DPFC acts as DPFC for one line and STATCOM or DVR for another line. The line1 has both shunt and series control whereas line2 has either shunt or series control depends on requirement. The simulated results of MC-DPFC systems show the effectiveness in power quality enhancement in the transmission lines.

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